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Industrial robot selection using a novel decision making method considering objective and subjective preferences

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ABSTRACT

Robots with vastly different capabilities and specifications are available for a wide range of applications. Selection of a robot from among the large number available in the market to suit a particular application and production environment has become a difficult task. Many methods for robot selection have been developed to date. Keeping in view the research works on industrial robot selection, a subjective and objective integrated multiple attribute decision making method is proposed in this paper for the purpose of robot selection. The method considers the objective weights of importance of the attributes as well as the subjective preferences of the decision maker to decide the integrated weights of importance of the attributes. Furthermore, the method uses fuzzy logic to convert the qualitative attributes into the quantitative attributes. Three examples are presented to illustrate the potential of the proposed method.

1. Introduction

An industrial robot is a general purpose, reprogrammable machine with certain anthropometrical features. The recent growth of information technology and engineering sciences have been the key reason for the increased utilization of robots in different advanced manufacturing systems. Robots can perform repetitious, difficult and hazardous tasks with precision. Therefore, manufacturers prefer to use robots in many industrial applications such as assembly, machine loading, materials handling, spray painting and welding. Hence, to improve product quality and to increase productivity, robot selection has always been a vital concern for manufacturing companies.

Robots with vastly different capabilities and specifications are available for a wide range of applications. Both the range of applications and the number of available industrial robots have increased substantially during the past several years. The robot selection problem is especially relevant bearing in mind the likely lack of experience of prospective users in employing a robot. Since industrial robots are usually costly and have many characteristics, their selection calls for a careful examination and assessment of the requirements. Various considerations such as product design, production system and economics need to be considered before a suitable robot can be selected. Improper selection of robots will adversely affect a company's competitiveness in terms of the productivity of its facilities and quality of its products. The selection of robots to suit a particular application and production environment from among the large number available in the market has become a difficult task. There have been a number of studies reported concerning the problem of robot selection over the last three decades, carried out by researchers, engineers, scientists and experts all over the world. Various considerations such as product design, production systems, cost, load capacity, man–machine interface, availability of diagnostic software, etc. need to be considered before a suitable robot can be selected. In general, these attributes can be classified into two categories [1]:

1. Objective attributes—these attributes are defined in numerical terms, e.g. cost, reliability, load capacity, repeatability, positioning accuracy, etc.
2. Subjective attributes—these attributes have qualitative definitions, e.g. vendor's service contract, training, man–machine interface, programming flexibility, etc.

Many precision-based methods for robot selection have been developed. Knott and Getto [2] suggested a model to evaluate different robotic systems under uncertainty and different alternatives were evaluated by computing the total net present values of cash flows of investment, labor components and overheads. Dooner [3] simulated robot operation in the workspace and used the workspace as an aid to robot selection. Hinson [4] stated that

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the working environment of the robot is a major factor for selection of robots. Huang and Ghandforoush [5] carried out evaluation and selection of robots based on the investment, and budget requirements etc. The marginal value function to evaluate and rank the robots was used by Jones et al. [6].

Offodile et al. [7] developed a coding and classification system which was used to store robot characteristics in a database, and then selected a robot using economic modeling. While the attempt provides a valuable aid at the stage of the final selection, such an exercise will be prohibitive at the initial selection stage where the number of potential robots are large and many other considerations have to be taken into account. Imany and Schlesinger [8] presented decision models for robot selection and compared ordinary least squares and linear goal programming methods.

Wang et al. [9] presented a decision support system which applies a fuzzy set method for robot selection. An expert system for industrial robot selection considering functional, organizational and economical factors in the selection process was developed [10]. Agrawal et al. [11] used a multiple attribute decision making approach known as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to evaluate, rank and select robots for particular application according to the requirements of the users. However, the TOPSIS method proposed by them does not take into account the qualitative nature of the robot selection attributes. Booth et al. [12] proposed a decision model for the robot selection problem using both Mahalanobis distance analysis (i.e. a multivariate distance measure) and principal-components analysis. Liang and Wang [13] proposed a robot selection algorithm by combing the concepts of fuzzy set theory and hierarchical structure analysis. Khouja and Offodile [14] reviewed the literature on the industrial robot selection problem and provided directions for future research. Khouja [15] presented a two-phase robot selection model that involved the application of data envelopment analysis (DEA) in the first phase, and a multi-attribute decision-making model in the second phase.

A revised weighted sum decision model was proposed in [16]. Parkan and Wu [17] presented decision-making and performance measurement models with applications to robot selection. A performance measurement procedure called operational competitiveness rating (OCRA) and a multiple attribute decision making method (TOPSIS) were used for decision making. The final selection was made on the basis of rankings obtained by averaging the results of OCRA, TOPSIS and a utility model. For selection of robots various techniques such as options theory and an investment evaluation procedure [18], investment evaluation using DEA [19], etc. have been presented.

Chu and Lin [1] pointed out the limitations of the Liang and Wang [13] method, and proposed a fuzzy TOPSIS method for robot selection. However, the authors had converted the available objective values of the robot selection attributes into fuzzy values, which violates the basic rule of fuzzy logic. Moreover, the fuzzy TOPSIS method involves more computation. Bhangale et al. [20] listed a large number of robot selection attributes, and ranked the robots using TOPSIS and graphical methods, comparing the rankings given by these methods. However, the weights assigned by the authors to the attributes were not consistent.

Rao and Padmanabhan [21] proposed a methodology based on digraph and matrix methods for evaluation of alternative industrial robots. However, the digraph and matrix approach may become complex if the number of attributes increases. Kahraman et al. [22] proposed a fuzzy hierarchical TOPSIS model with an application for the multi-criteria evaluation of industrial robotic systems. Karsak [23] introduced a decision model for robot selection based on quality function deployment (QFD) and fuzzy linear regression. Chatterjee et al. [24] attempted two methods 'VIsekriterijumsko KOmpromisno Rangiranje' (VIKOR) and 'ELimination and Et Choice Translating REality' (ELECTRE) and compared their relative performance for a given industrial application. However, VIKOR and ELECTRE methods are outranking methods, having no axiomatic foundation, and require comparatively more computation. Kumar and Garg [25] developed a deterministic quantitative model based on the Distance Based Approach (DBA) method for evaluation, selection and ranking of robots. However, the DBA method proposed by them does not take into account the qualitative nature of the robot selection attributes.

Keeping in view the above research works on robot selection, a novel decision making method is proposed in this paper for robot selection for a given industrial application. The aim of the present paper is to propose a novel MADM method to deal with robot selection problems, considering both qualitative and quantitative attributes. A ranked value judgment on a fuzzy conversion scale for the qualitative attributes is introduced. The proposed method helps the decision maker to arrive at a decision based on either the objective weights of importance of the attributes or his subjective preferences, or considering both the objective weights and the subjective preferences. Three examples are included to illustrate the proposed method.

2. Proposed multiple attribute decision making methodology

Multiple attribute decision making (MADM) is employed to solve problems involving selection from among a finite number of alternatives. Each decision table in MADM methods has four main parts, namely: (a) alternatives, (b) attributes, (c) weight or relative importance of each attribute, and (d) measures of performance of alternatives with respect to the attributes. The decision table shows alternatives, A_i (for $i = 1, 2, \ldots, n$), attributes, B_j (for $j = 1, 2, \ldots, m$), weights of attributes, w_j (for $j = 1, 2, \ldots, m$) and the measures of performance of alternatives, y_{ij} (for $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$). Given the decision table information and a decision making method, the task of the decision maker is to find the best alternative and/or to rank the entire set of alternatives. It may be added here that all the elements in the decision table must be normalized to the same units so that all possible attributes in the decision problem can be considered.

The methodology presented in this paper for robot selection is described below:

Step 1: preparation of the decision table.

Identify the selection attributes for the considered robot selection problem and shortlist the robots on the basis of the identified attributes satisfying the requirements. The attributes are of two types, beneficial (i.e. higher values are desired) and non-beneficial (i.e. lower values are desired). A quantitative or qualitative value or its range may be assigned to each identified attribute as a limiting value or threshold value for its acceptance for the considered problem. An alternative with each of its attribute, meeting the acceptance value, may be shortlisted. After shortlisting the alternatives and determining the values associated with the attributes (y_{ij}), a decision table including the measures or values of all attributes for the shortlisted alternative robots, can be prepared and the values of the attributes can be normalized for different alternatives using Eq. (1).

$$y^*_{ij} = y_{ij} / \sum_{i=1}^{n} y_{ij}, \tag{1}$$

where y^*_{ij} is the normalized value of y_{ij}.

It may be added here the Eq. (1) can deal with quantitative attributes. However, there exists some difficulty in the case of qualitative attributes (i.e. a quantitative value is not available). A ranked value judgment on a fuzzy conversion scale is proposed in this paper by using fuzzy set theory. This approach is based on the works